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**Hanks**

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(54) **AUTOMATED SOIL ANALYSIS SYSTEM**

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(76) **Inventor:** **Dallas A. Hanks, 1319 S. 1180 West,  
Orem, UT (US) 84058**

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(\*) **Notice:** Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

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**Primary Examiner**—Daniel S. Larkin

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(74) **Attorney, Agent, or Firm**—Pate Pierce & Baird

**Related U.S. Application Data**

**(57) ABSTRACT**

(63) Continuation-in-part of application No. 08/985,498, filed on Dec. 6, 1997, now Pat. No. 5,974,899.

(60) Provisional application No. 60/031,488, filed on Dec. 6, 1996.

(51) **Int. Cl.**<sup>7</sup> ..... **G01N 33/24**

(52) **U.S. Cl.** ..... **73/863.12; 73/866; 422/68.1**

(58) **Field of Search** ..... **73/863.12, 863,  
73/863.11, 866; 422/68.1; 436/81, 79, 103,  
110, 119**

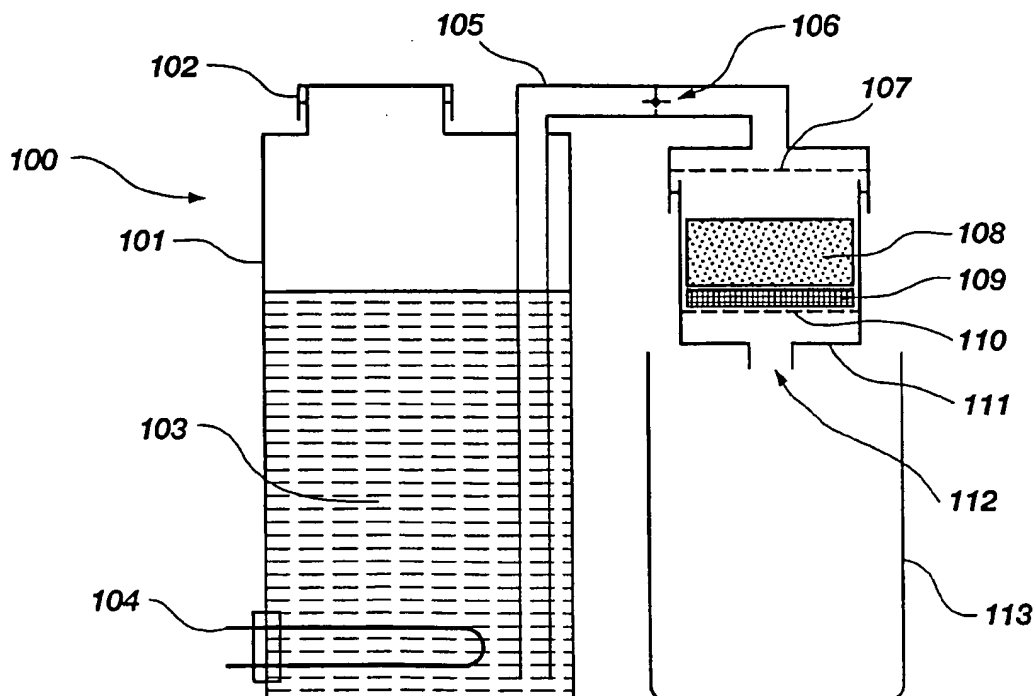
A method for supplying fertilizer to a lawn, garden, golf course, farm, field, or other agricultural growing area. The method may include the steps of obtaining a soil sample from the agricultural area, measuring a nutrient content of the soil sample with a soil analyzer device, obtaining data for the size of the agricultural area, and electronically calculating the fertilizer required for the agricultural area based upon the soil nutrient analysis and area size data. In certain embodiments, the measuring step may include the steps of passing water heated to a temperature of at least 90° C. through the sample under pressure of at least 2.0 bar, collecting the water passed through the sample, and analyzing the nutrients transferred from the soil to the water.

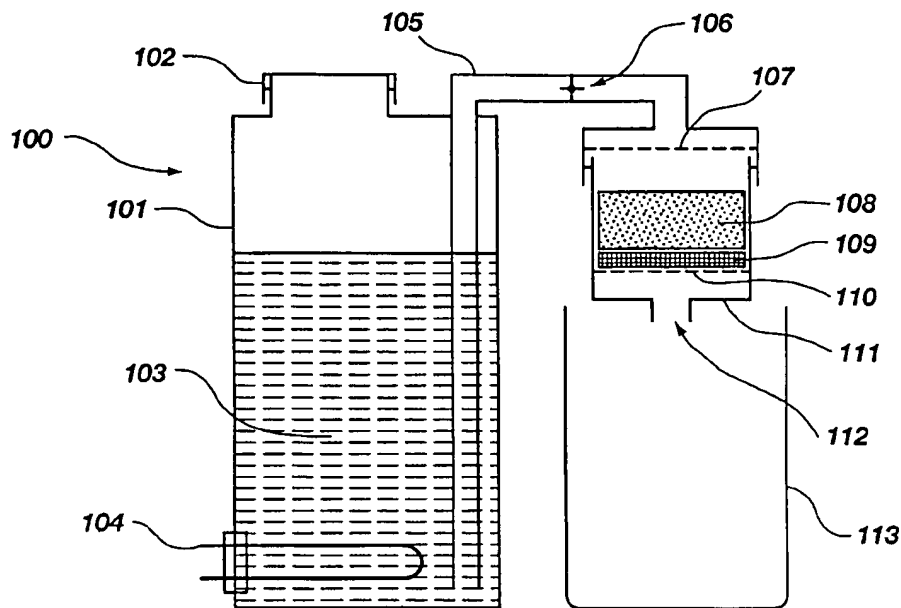
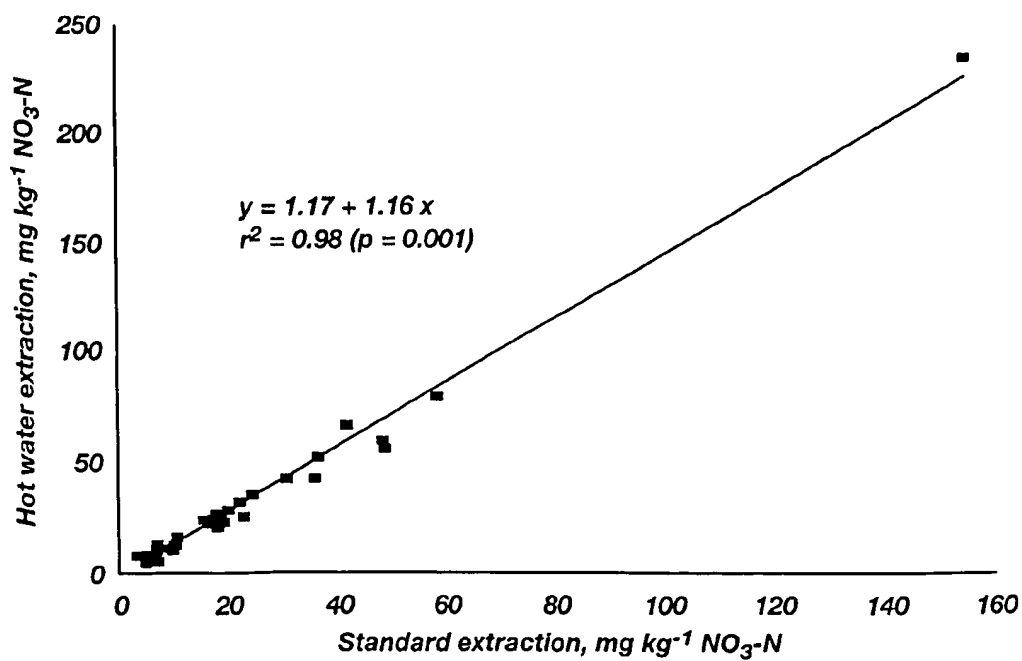
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**2 Claims, 3 Drawing Sheets**



**Fig. 1****Fig. 2**

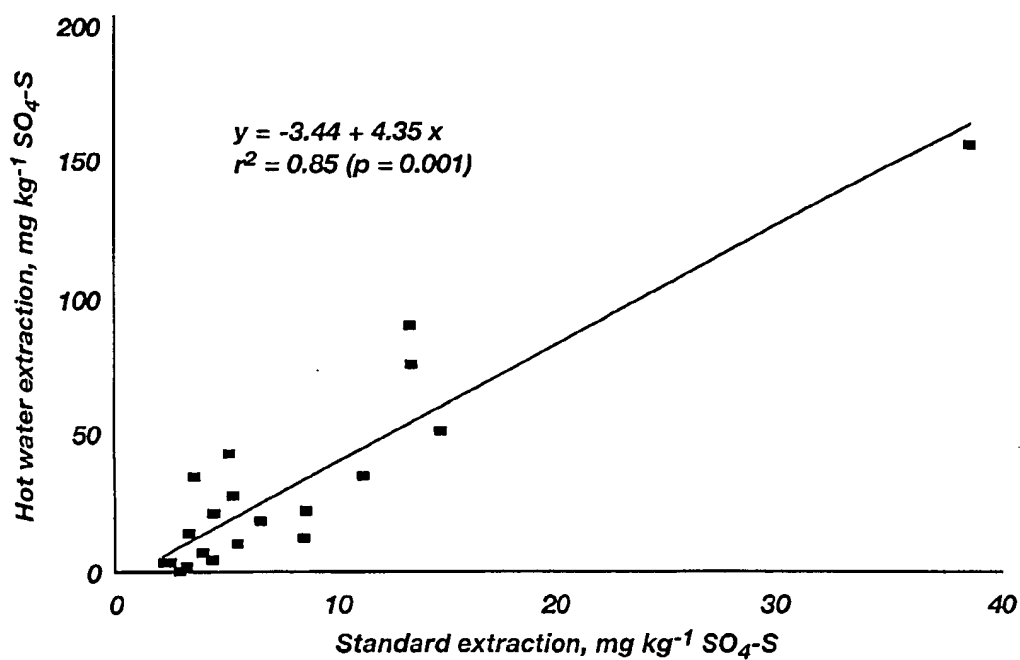


Fig. 3

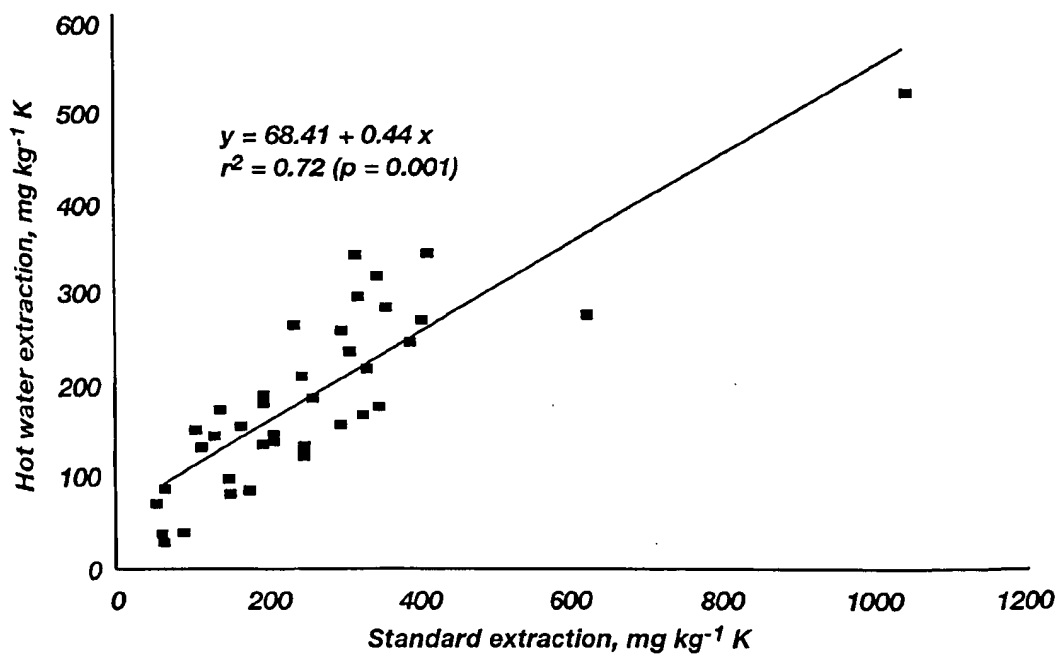


Fig. 4

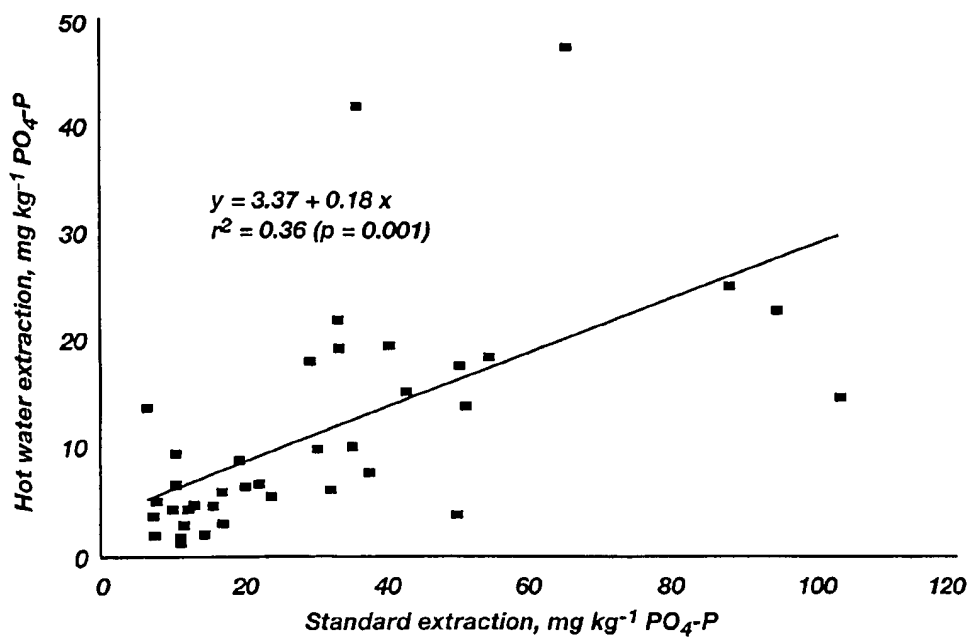


Fig. 5

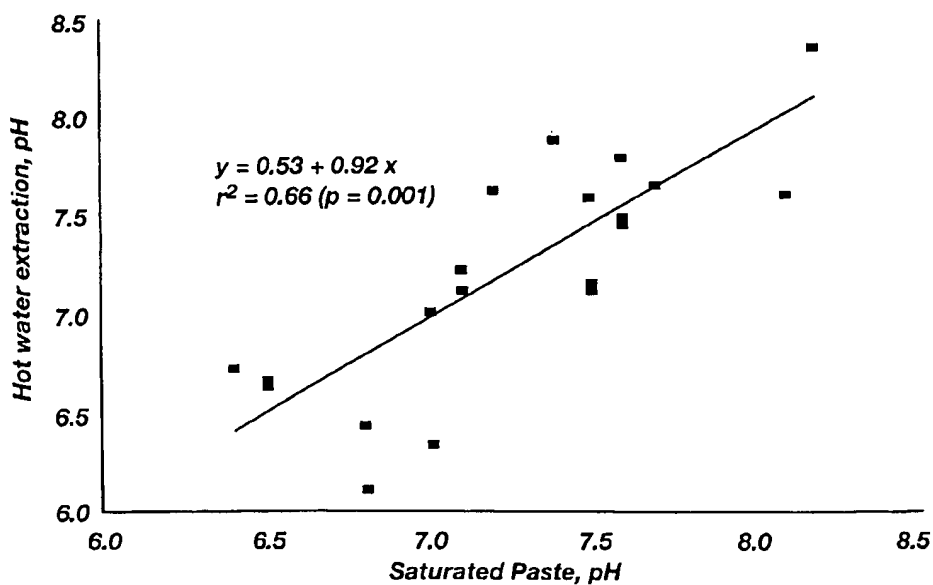


Fig. 6

## AUTOMATED SOIL ANALYSIS SYSTEM

## RELATED PATENT APPLICATION

This invention is a continuation-in-part of U.S. patent application Ser. No. 08/985,498, filed Dec. 5, 1997, now U.S. Pat. No. 5,974,899, which claims the benefit of U.S. Provisional Patent Application Ser. No. 60/031,488, filed Dec. 6, 1996, which applications are incorporated herein by reference.

## BACKGROUND OF INVENTION

## 1. Field of the Invention

This invention relates to soil nutrient extraction methods and, more particularly, to hot water nutrient extraction systems that are automated and coupled to computer systems for determining fertilizer requirements.

## 2. Description of Related Art

Increasing demand for soil analysis, prompted by environmental and economic factors, has intensified the need for an inexpensive, fast, convenient, and precise extraction method. Wet chemistry extractions for soil analyses are often labor intensive, complicated, or environmentally hazardous. The extractions are generally tedious, typically involve expensive equipment, require considerable laboratory space, and normally involve the use of numerous chemical reagents. These factors render contemporary soil analysis method prohibitively expensive for all but the most serious agronomic and horticultural pursuits. Simplified soil analysis procedures, if commercially available, are unlikely to extract multiple nutrients in one step and generally require varied reagent use for extractions.

The search for simple, one-step, nutrient extraction method utilizing hot water was probably initiated in the twentieth century by Konig (1906). Anion exchange resin, in combination with water, has been used to measure the total desorption of phosphorus (Amer, et al., 1955). Van der Paaus (1969) proposed that phosphorus (P) extraction efficiency could be improved by using a soil-water ration of 1:50. Korschens, et al. (1984) used the Soxhlet extraction technique, which utilized water, to extract and measure carbon (C) and nitrogen (N) in soils. Suntheim and Matzel (1985) used a continuous water extraction technique to determine phosphorous content in soils. Most recently, a hot water percolation method to extract both macro and micro nutrients was reported for acidic soils of Hungary by Fulkey and Czinkota (1993). Using this method, a mixture consisting of a 30 g soil sample and 10 g of sand was placed on the filter of a coffee percolator and water preheated to 102–105° C. was percolated through the sample under a pressure of 120 to 150 kilopascals (equivalent to about 1.2 to 1.5 bar or 17.4 to 21.75 lbs./in<sup>2</sup>) until about 100 to 500 ml of extract were collected. Results obtained from this latter extraction process compared favorably with plant uptake experiments for acidic soils. Fulkey and Czinkota determined that the time required to obtain 100 ml of extract for percolation through pure soil samples averaged Forty one minutes, while an average of one hundred eighty-eight minutes was required to obtain 500 ml of extract. Because of such unreasonably long percolation times, they determined that it was necessary to dilute the soil samples with sand. They determined that too much sand resulted in such rapid percolation that the amount of nutrients released into the accumulated extract was insufficient for accurate quantitative analysis of the soil sample. Through trial and error, it was determined that a mixture of 25% sand and 75% soil sample, by weight, provided the best combination of rea-

sonable percolation times an average of 2.6 minutes for 100 ml of extract) and adequate release of nutrients into the extract.

What is needed is an improved method for hot water extraction of nutrients from soil samples which is inexpensive, rapidly performed, capable of providing excellent analytical results for a variety of nutrients, and which does not require the mixing of sand with a soil sample. Ideally, such an improved method would make use of readily available equipment which could be used, without modification, to practice the improved method, or which could be readily and inexpensively modified for such practice.

## SUMMARY OF THE INVENTION

The invention fills the heretofore expressed need for an improved method of extracting nutrients from soil samples using hot water. The improved method forces pressurized hot water through soil samples to which no filler materials, such as silica sand, had been added. Tests were performed with a Braun model E-250T espresso machine supplied by Braun, Inc., Lynnfield, Mass.). The E-250T generates a pressure of 2.5 bar and a temperature of 93° C.

The method was performed with the following steps. Soils to be tested were air dried at a maximum temperature of 25° C. and passed through a 2.0 mm (number 10 mesh) screen. A 5.0-gram soil sample was placed in the espresso machine's filter basket, which was lined with a 5.50-cm diameter medium filter paper. 100 ml of distilled water was placed in the espresso machine's boiler, and allowed to heat for 2.0 minutes. The heated water was released and passed through the soil sample until the boiler was empty and the filter basket without surface water. This generally occurred in 0.5 to 5 minutes. Extraction aliquots were allowed to cool and the volumes measured (the measured volumes, which ranged from 64 to 91 ml, averaged 79 ml. 10 ml samples from the extraction aliquots were tested for various soil nutrients. Nitrate (NO<sub>3</sub>) content was quantified colorimetrically by using a chromatropic acid procedure according to Sims and Jackson (1971). Clarity of the sample for nitrate was determined by adding 0.35 grams of Ca(OH)<sub>2</sub> to a 10 ml sample, the mixture was shaken for five seconds, centrifuged at 2,000 RPM for Forty-Five seconds, and the resultant solution used in nitrate analysis. Sulfate (SO<sub>4</sub>) content was determined using an ion chromatograph. Potassium (K) content was analyzed using an atomic absorption spectrophotometer. The pH value for the sample was determined with a conventional pH meter. Phosphorus (P) content was determined colorimetrically using a molybdenum-blue procedure according to Watanabe and Olsen (1965).

For comparison and calibration purposes, the same soils analyzed using the new hot water extraction method were also analyzed for nitrate content, sulfate content, potassium content, phosphorus content, and pH using widely-recognized standard methods. The procedures used are hereinafter identified. Linear regression analysis was employed to predict the relationship between the nutrient values obtained using the new hot water method and the nutrient values obtained via the standard nutrient analysis procedures.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic diagram of the apparatus used to practice the soil nutrient extraction method of the present invention;

FIG. 2 is a graph of the predicted relationship between nitrate nitrogen extracted from thirty-eight arid-zone soils by hot water and standard extraction methods;

FIG. 3 is a graph of the predicted relationship between sulfate sulfur extracted from twenty arid-zone soils by hot water and standard extraction methods;

FIG. 4 is a graph of the predicted relationship between potassium extracted from thirty-eight arid-zone soils by hot water and standard extraction methods;

FIG. 5 is graph of the predicted relationship between phosphate phosphorus extracted from thirty-eight arid-zone soils by hot water and extraction methods; and

FIG. 6 is a graph of the predicted relationship between pH of twenty arid-zone soils measured on a saturated paste and on the hot water extract.

#### PREFERRED EMBODIMENT OF THE INVENTION

Hot water extraction has been shown to be an effective method for determining the amounts of various important nutrients present in soil samples. In addition, the derived analytical results have been shown to correlate favorably with those obtained using conventional soil analysis methods. This invention provides a rapid and greatly simplified method for performing hot water extraction of soil nutrients. The improved method utilizes a high-pressure nutrient extraction apparatus, such as an espresso coffee machine, to force hot water through soil samples.

For comparison and calibration purposes, thirty-eight different arid-zone soil samples were analyzed for texture, nutrient content, and pH using widely-recognized standard methods. Nitrate content was determined via a procedure developed by Kowalenko and Lowe (1973); sulfate content via a procedure devised by Williams and Stanely (1962); potassium content via a procedure recognized by the Council on Soil Testing and Plant Analysis (1980); phosphorus content via a procedure developed by Wantanabe and Olsen (1965); and pH using a standard saturated paste method devised by Richards (1954). Extractions were replicated three times with a randomized complete block design. The results from the new hot water method and the standard extraction procedures were correlated using a technique developed by Goulden (1952). Linear regression analysis was employed to predict the relationship between the nutrient values obtained using the new hot water method and the nutrient values obtained via the standard nutrient analysis procedures. The following Table 1 provides results of the standard method analyses.

TABLE 1

Sand	Silt	Clay	Texture	NO <sub>3</sub>	P	K	SO <sub>4</sub>	pH
--- % by weight ---				--- mg/Kg ---				
22.9	30.9	46.2	clay loam	17.7	35.3	246.4	*	*
N/A	N/A	N/A	N/A	17.8	50.2	320.0	*	*
20.9	28.9	50.2	clay loam	47.8	33.4	192.0	*	*
N/A	N/A	N/A	N/A	6.6	12.0	403.2	*	*
N/A	N/A	N/A	N/A	25.5	94.8	137.6	*	*
70.6	12.9	16.5	sandy loam	48.2	103.3	131.2	*	*
64.6	12.9	22.5	sandy loam	5.2	10.9	105.6	*	*
20.6	38.9	40.5	clay loam	9.1	14.3	387.2	*	*
50.6	32.9	16.5	sandy clay loam	4.2	17.0	246.4	*	*
41.5	30.9	27.6	clay loam	9.9	29.7	172.8	*	*
38.2	28.9	32.9	clay loam	5.5	23.7	243.2	*	*
32.2	38.9	28.9	clay loam	5.8	11.0	256.0	*	*
50.2	28.9	20.9	sandy clay loam	4.6	12.6	291.2	*	*
38.5	26.9	34.5	clay loam	6.6	50.9	1052.8	*	*
32.2	32.9	34.9	clay loam	9.7	15.7	112.0	*	*

TABLE 1-continued

Sand	Silt	Clay	Texture	NO <sub>3</sub>	P	K	SO <sub>4</sub>	pH
40.6	28.9	30.5	clay loam	22.6	10.3	342.4	*	*
38.6	28.9	32.5	clay loam	8.19	7.6	67.2	*	*
40.6	28.9	30.5	clay loam	18.9	32.0	54.4	*	*
39.9	11.0	49.1	loam	6.1	36.2	346.7	*	*
65.5	25.0	9.4	sandy clay loam	6.0	7.0	58.7	2.0	6.8
88.0	4.7	7.4	sand	10.3	19.4	316.8	3.4	7.5
26.6	28.7	44.7	clay loam	41.4	37.4	316.8	42.1	8.1
54.6	30.3	15.1	sandy clay loam	21.7	42.6	304.0	76.0	7.7
20.6	26.3	53.1	silty clay loam	3.9	7.4	60.8	0.7	6.4
20.6	26.3	53.1	clay	17.7	11.3	145.1	36.6	6.5
74.2	23.7	2.1	sandy clay loam	3.5	10.4	88.5	3.3	6.5
38.9	20.4	40.7	loam	2.9	54.4	150.4	7.1	7.0
30.6	10.7	58.7	silt loam	30.3	49.5	232.5	27.7	7.6
38.2	38.7	23.1	clay loam	15.1	65.8	205.9	13.9	6.8
37.5	18.7	43.8	loam	19.8	33.4	330.7	20.9	7.0
25.2	38.7	36.0	clay loam	17.6	40.7	203.7	22.5	7.5
22.2	38.0	39.8	clay loam	17.0	20.1	165.3	18.6	7.6
38.2	53.7	8.0	clay	24.0	9.7	352.0	4.9	7.2
26.2	28.3	45.4	clay loam	36.1	88.0	295.5	50.6	7.6
22.2	25.3	52.4	silt loam	15.9	17.0	195.2	10.3	7.4
46.9	19.0	34.1	loam	18.4	6.7	624.0	12.7	8.2
40.6	26.4	33.1	loam	155.8	22.0	196.3	90.5	7.1

N/A Remnants of samples were not large enough for textural analysis.

\*: These soils were not included in the study on pH and sulfate

FIG. 1 depicts a schematic diagram of a high-pressure extraction apparatus 100 employed in conjunction with the new hot water nutrient extraction method. The Braun model E-250T espresso machine, supplied by Braun, Inc. of Lynnfield, Mass. is one such apparatus that is suitable for use with the new hot water nutrient extraction method. The E-250T generates water pressure of 2.5 bar and a temperature of 93° C. Referring now to FIG. 1, a pressure chamber 101 is sealably capped with a removable lid 102 after being filled with distilled water 103. A heating coil 104 heats the water 103 to near boiling temperature. A pressure tube 105 interconnects the pressure chamber with a sample holder 111 that is sealably connected to the pressure tube 105. Valve 106 is maintained in a closed position until the water 103 reaches the desired temperature. Within a temperature range of 90 to 100° C., the most significant soil nutrients are sufficiently soluble to enable accurate analysis using conventional techniques. However, as temperatures beyond this range will provide increased solubility of nutrients, the method may be employed, at least theoretically, at temperatures below which nutrient decomposition begins to take place. As a practical matter, though, temperatures near and above boiling pose at least some risk of burning and scalding to the individual performing the extraction. In addition, energy is wasted by heating the water beyond temperatures required for accurate analysis. At pressures of much less than 2.0 bar, the time required to complete the extraction process becomes inconveniently long unless a filler material such as sari is added to the sample. The sample holder 111 has a perforated sampled support plate 110. A medium filter paper 109 is placed directly on the support plate 110, and the soil sample 108 is placed on top of the filter paper 109. When the valve 106 is opened after optimum water temperature is achieved, the water flows from the pressure vessel 102 through pressure tube 105, through the diffused plate 107, through the soil sample 108, through the filter paper 109, through the perforated support plate, through the escape opening 112 and into a collection flask 113. The hot water passed through the soil samples is collected and

analyzed. The method utilizes air-dried soil samples to which no tiller materials such as silica sand have been added.

Soil nutrients analysis for the same thirty-eight samples was then performed via the new hot water method using the following steps. Each soil sample was air dried at a maximum temperature of 25° C. and passed through a 2.0 mm (number 10 mesh) screen. A 5.0 gram mass of each sample was then placed in the espresso machine's filter basket, which was lined with a 5.50-cm diameter medium filter paper. 100 ml of distilled water was placed in the espresso machine's boiler, and allowed to heat for 2.0 minutes. The heated water was released and passed through the 5.0-gram sample until the boiler was empty and the filter basket without surface water. This generally occurred in 0.5 to 5 minutes. Extraction aliquots were allowed to cool and the volumes measured (the measured volumes, which ranged from 64 to 91 ml, averaged 79 ml. 10 ml samples from the extraction aliquots were tested for various soil nutrients. Nitrate ( $\text{NO}_3$ ) content was quantified colorimetrically by using a chromatropic acid procedure according to Sims and Jackson (1971). Clarity of the sample of nitrate was determined by adding 0.35 grams of  $\text{Ca}(\text{OH})_2$  to a 10 ml sample, the mixture was shaken for five seconds, centrifuged at 2,000 RPM for Forty-Five seconds, and the resultant solution used in nitrate analysis. Sulfate ( $\text{SO}_4$ ) content was determined using an ion chromatograph. Potassium (K) content was analyzed using an atomic absorption spectrophotometer. The pH value for the sample was determined with a conventional pH meter. Phosphorus (P) content was determined colorimetrically using a molybdenum-blue procedure according to Watanabe and Olsen (1965).

As depicted by Table 1, the thirty-eight different soils tested were diverse in pH, texture and nutrient content. One step extraction with hot water provided measurable quantities of  $\text{NO}_3$ ,  $\text{SO}_4$ , K, and P in all thirty-eight calcareous soils tested. The correlation coefficient ( $r$ ) of hot water extractions with standard methods ranged from 0.99 to 0.60. Resulting regression equations and statistically significant coefficients of determination allow conversion to "standard" values for interpretation.

Nitrate values for the thirty-eight soils using standard extraction methods ranged from 4 to 233  $\text{mg}\cdot\text{kg}^{-1}$  (Table 1) and from 3 to 156  $\text{mg}\cdot\text{kg}^{-1}$  nitrate nitrogen using the new hot water extraction method (FIG. 1). The relationship between the hot water method and the standard methods was excellent [ $r^2=0.98$  ( $p<0.001$ )]. Thus, effective removal of nitrate was achieved with the new extraction method. These results are not surprising given the high water solubility of nitrate.

Sulfate values for the twenty soils tested using standard extraction methods ranged from 2 to 159  $\text{mg}\cdot\text{kg}^{-1}$  (Table 1) and from 2 to 39  $\text{mg}\cdot\text{kg}^{-1}$  sulfate sulfur using the new hot water extraction method (FIG. 2). Extraction values from the two techniques were closely related [ $r^2=0.85$  ( $p=0.001$ )] (FIG. 2). As for nitrate, the high water solubility of sulfate would suggest that a close correlation would be found.

Potassium values for the thirty-eight soils using standard extraction methods ranged from 54 to 1,053  $\text{mg}\cdot\text{kg}^{-1}$  (Table 1) and from 26 to 522  $\text{mg}\cdot\text{kg}^{-1}$  using the new hot water method. The coefficient of determination from the regression equation comparing the two techniques was [ $r^2=0.72$  ( $p=0.001$ )]. As potassium levels approached 400  $\text{mg}\cdot\text{kg}^{-1}$  (values well above the critical concentrations for the recommendation of fertilizer), the new hot water technique was unable to extract as effectively as the standard method.

Phosphorus values determined using standard methods ranged from 7 to 103  $\text{mg}\cdot\text{kg}^{-1}$  (Table 1) and from 1 to 47  $\text{mg}\cdot\text{kg}^{-1}$  phosphate phosphorus using the new hot water extraction method (FIG. 4). Expectedly, phosphate levels determined with the hot water method were lower than with the standard method. However the correlation between the values obtained using the hot water method and those obtained using the standard method was significant [ $r^2=0.35$  ( $p=0.001$ )].

Phosphorus content in western soils is traditionally regarded as being tightly held in a calcium phosphate complex which makes extraction difficult using hot water. Thus, the significant relationship observed was a surprise. The relationship can probably be improved by, for example, increasing either, or possibly both, the temperature and the pressure of the water, or by changing the water to soil ratio used in the extraction process.

The pH on saturated pastes for the twenty soils tested ranged from 6.4 to 8.2 (Table 1) and, using the new hot water extraction method, from 6.1 to 8.3 (FIG. 5). Values from the two techniques were predictably related [ $r^2=0.67$  ( $p=0.001$ )]. Thus, extractions using the new hot water method are adequate to measure pH in alkaline soils.

From the above results, it can be readily observed that the new hot water extraction method is effective for measuring nitrate, phosphate, sulfate, potassium, and pH. The method provides good correlation to standard extraction procedures in alkaline soils, thus allowing easy conversion of hot water extraction values to standard values. It should be emphasized that the correlations derived from the results obtained in the experiments discussed herein are valid for water temperatures of 93° C. and for the extraction aliquots obtained starting with 100 ml of water. Variations from these parameters will require recalibration of the results obtained. The new method can be performed rapidly with no chemical extractants and requires no dilution of the soil sample with a filler, such as silica sand. The equipment used for the new extraction method is commercially available, simple to use, and relatively inexpensive. The use of hot water for the extraction process reduces the dependence on chemicals used in standard extractions.

The present invention includes an automated system for analyzing soil samples. The process includes the steps of obtaining a soil sample to be tested. Typically, a 5 gram sample size is sufficient, but larger and smaller sample sizes can be used. The soil sample can be moist or dry. The quantity of the sample, volume and weight, is preferably measured. High temperature water, heated to a temperature of at least 90° C. and pressurized to a pressure of at least 2 bars, is passed through the sample. The water temperature and pressure is preferably computer controlled and monitored. The water passing through the sample is collected and analyzed. The analysis is preferably computer controlled. Macro nutrients in the soil sample are determined, such as nitrogen, phosphorus, and potassium. Selected micronutrients are also preferably measured, such as copper, zinc, and iron. Other soil parameters can be measured, such as electrical conductivity, organic matter, texture, and sodium absorption ratio (SAR). It is also possible to measure certain environmental components, such as heavy metals. Typical heavy metals which are measured according to the present invention include arsenic, lead, and cadmium. Certain organic molecules can also be measured, such as PCB's, pesticides, oils, solvents, etc. Based upon the analysis, the soil type and fertilizer needs can be determined. When combined with lawn or garden area size, the precise quantity and type of fertilizer can be readily determined and reported to the user.

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In one currently preferred embodiment, the foregoing soil analyzer is linked by computer to an automated fertilizer dispenser which dispenses and bags the appropriate type and quantity of fertilizer based upon the soil sample and lawn or garden area size. In operation, the consumer places the soil sample within a sample chamber and inputs the lawn or garden area size. The soil is analyzed. The appropriate type and quantity of fertilizer is dispensed and bagged for the consumer to purchase. It is also possible to integrate payment for the fertilizer through use of conventional credit card payment systems.

In another preferred embodiment, the system can be configured for mobile operation. For instance, the system can be equipped onto a tractor used in larger scale farming operations. Periodic soil samples can be drawn and analyzed. Based upon the analysis, variations in the type and quantity of fertilizer can be dispensed from the same tractor or from another tractor in electronic communication with the first tractor.

The system can also be made portable for mobile operation. The operator can take the system to the field or fields to obtain soil analysis on site.

In an alternative preferred embodiment, the soil analyzer prepares a fertilizer requirements report to be used by the consumer in purchasing his or her fertilizer requirements.

Although the foregoing discussion has focused on the analysis of soil samples, the present invention can be readily

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adapted and used for direct analysis of plant material, such as leaf, root, or stem analysis. Such plant analysis can then be used to electronically determine appropriate fertilizer requirements for the specific plants in a manner similar to the process discussed above.

What is claimed is:

1. A method for supplying fertilizer for a lawn, garden, golf course, farm, field, or other agricultural growing area comprising the steps of:

obtaining a soil sample from the agricultural area;

measuring a nutrient content of the soil sample with a soil analyzer device by passing water at a temperature of at least 90° C. through the sample under a pressure of at least 2.0 bar, collecting the water passed through the sample, and analyzing the nutrients transferred from the soil to the water;

obtaining data for the area size of the agricultural area; and

electronically calculating the fertilizer required for the agricultural area based upon the soil nutrient analysis and area size data.

2. A method for supplying fertilizer for a lawn or garden according to claim 1, further comprising the step of dispensing the fertilizer requirements.

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